



# Effective parameters for DME steam reforming catalysts for the formation of H<sub>2</sub> and CO

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## ABSTRACT

Recently, DME has received attention as a clean fuel and is now considered an alternative fuel for diesel engines. DME diesels need de-NO<sub>x</sub> catalysts such as LNT (Lean NO<sub>x</sub> Trap) and SCR (Selective Catalytic Reduction) systems. DME is an attractive source of hydrogen because it can be stored easily and is a good transportation fuel. Hydrogen and CO enriched gas as a reductant was used with the LNT catalyst in order to reduce NO<sub>x</sub> emissions. The steam reforming catalyst of DME was used to formation of hydrogen. It has been reported that Cu-based catalysts have high selectivity and activity in the steam reforming of DME. This research used 600 cPsi cordierite as a catalyst, which was coated with copper. The catalysts were made via a sol–gel and impregnation methods. The formation of H<sub>2</sub> and CO under the prepared catalysts was tested by a model gas. Experimental parameters were considered; the space velocity (SV) and concentrations of H<sub>2</sub>O, O<sub>2</sub>, and CO<sub>2</sub> were evaluated. The Cu 30%/γ-Al<sub>2</sub>O<sub>3</sub> catalyst from the sol–gel method exhibited high and stable activity in the production of hydrogen from the steam reforming of DME. Both DME conversion and the selectivity of hydrogen were affected by SV and the concentrations of H<sub>2</sub>O, O<sub>2</sub>, and CO<sub>2</sub>.

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## 1. Introduction

Due to their high thermal efficiency, diesel engines cause low emissions of CO<sub>2</sub>, which is a global warming material, while the application of an emission after-treatment system is essential because PM and NO<sub>x</sub> have a trade-off relationship due to the characteristics of diesel combustion. DME (dimethyl ether), which is easily applicable to diesel engines, has high possibility as an alternative fuel for diesel engines [1,2]. DME has excellent self-ignition characteristics, a high cetane number, and similar physical properties to LPG fuel; therefore, it can be used for most existing infrastructures, making it favorable for commercialization. DME contains about 34.5% of oxygen in the fuel; so, it is advantageous in terms of generating little PM by suppressing the creation of soot [3]. However, the generation of NO<sub>x</sub> may increase; therefore, an after-treatment is necessary for its reduction. Various engine-related technologies such as EGR, new combustion conceptions, are under development to reduce NO<sub>x</sub> [4,5]; however, the application of an emission after-treatment device is essential to meet new – and more stringent – regulations on emission. Various reduction methods such as LNT, Urea-SCR [6], and HC-SCR are well

known as catalysts for reducing NO<sub>x</sub> [7]. Urea-SCR is commercialized for automobiles; however, the large volume of such systems and the associated inadequate infrastructure for supplying urea-aqueous solutions are challenges to the commercialization of such systems. On the other hand, LNT can effectively reduce the NO<sub>x</sub> that is adsorbed through a reductant (H<sub>2</sub>, CO, HC, etc.) that is obtainable from the post-injection of fuel without a separate device [8]. As a reductant for LNT catalysts, hydrogen is favorable for the activation of de-NO<sub>x</sub> at low temperatures. Meanwhile, DME is attracting more interest as a hydrogen carrier to supply hydrogen to fuel cells. This is because it is possible to create H<sub>2</sub> by easily reforming DME at low temperatures [9–11]. However, most catalysts cause a pressure drop in pellet-type reactors, facilitate wear and fragility through collision with each other, and are weak against thermal deactivation [12]. Methods such as steam reforming, partial oxidation, and autothermal reforming are used to produce H<sub>2</sub> from DME. DME steam reforming has an advantage of high H<sub>2</sub> production compared of other reforming method. However, the papers did not mention any supply of external heat sources although it is an endothermic reaction. Partial oxidation and autothermal reforming are exothermic reactions; therefore, they have the advantages of requiring no separate heat source and being fast in the reaction time. However, compared to steam reforming, they have the disadvantage of creating lower H<sub>2</sub> selectivity and a higher level of side reactions and by-products

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[13]. Precious metallic catalysts to reform DME are very active at low temperatures; however, they generate methane that reduces the H<sub>2</sub> selectivity [10]. On the other hand, it is reported that when a DME steam reforming reaction is conducted using a Cu catalyst, H<sub>2</sub> starts to form at a reaction temperature of 227 °C and its concentration increases up to a temperature of 600 °C, the major products of the reaction being H<sub>2</sub>, CO, CH<sub>4</sub>, and CO<sub>2</sub> [13]. Possessing high H<sub>2</sub> selectivity, a Cu catalyst using steam reforming triggers a DME hydrolysis reaction (Eq. (1)), MeOH steam reforming (Eq. (2)), and a water-gas shift reaction [14–16].

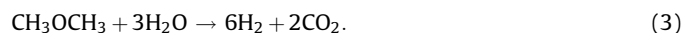
DME hydrolysis:



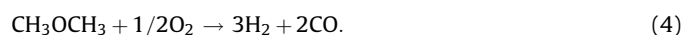
MeOH steam reforming:



DME steam reforming:



DME partial oxidation:



Recently, research has been conducted on the reaction characteristics of reforming catalysts for use in hybrid DME engines [17] and the application of DME as a reductant for LNT [18]. However, there is lack of research on the basic factors that affect a DME reforming reaction; for most DME reforming reaction characteristics, only the effect of the H<sub>2</sub>O and DME supply quantities is evaluated by powder or pellet-type catalysts. Thus, this study aims to investigate various parameters that affect the formation of hydrogen in order to efficiently use hydrogen as a reductant for LNT catalysts for DME diesel engines. For application to a DME vehicle, we selected a cordierite (600 cPsi) honeycomb-type substrate that is currently used to most of the after-treatment system of the gasoline and diesel vehicles. Then the catalyst samples were coated with washcoat on the substrate. The considered parameters include the effect of catalyst washcoat manufacturing methods, space velocity (SV), and the components of the considered exhaust emissions are O<sub>2</sub>, H<sub>2</sub>O, and CO<sub>2</sub> concentration. Thus, this study aims to present the most efficient conditions for the factors that affect H<sub>2</sub> selectivity due to a DME steam reforming reaction.

## 2. Experimental

### 2.1. Preparation of catalysts

The catalysts used in the experiment were manufactured through the sol–gel method [19] and an impregnation method. Copper (Cu) was basically used as the catalyst, and as shown in Table 1, the Cu loading quantities of the catalyst manufactured in the sol–gel method were 10, 20, 30, and 40 wt% of the washcoat [20], while the Cu loading quantities of the catalyst manufactured

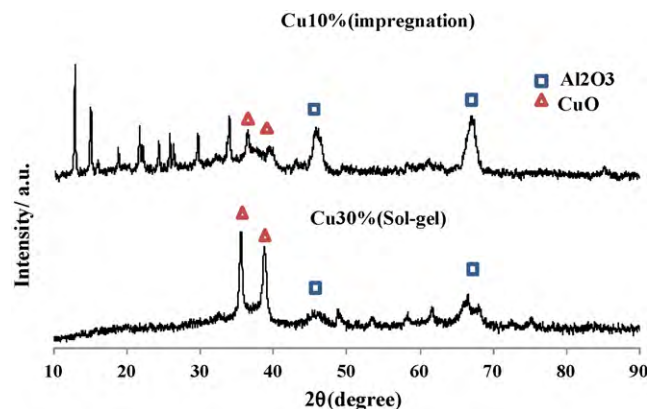
in the impregnation method were 5 and 10 wt% of the washcoat. This experiment used a DME steam reforming reaction to enhance the H<sub>2</sub> selectivity. A steam reforming reaction refers to a reaction to generate H<sub>2</sub> through a reacting fuel such as hydrocarbon and alcohol, with water under the presence of catalysts. These fuels are transformed into H<sub>2</sub>, CO, and CH<sub>4</sub> via a steam reforming reaction, with the advantage of high H<sub>2</sub> selectivity. The process of manufacturing a catalyst in the sol–gel method is as follows. Aluminum isopropoxide (Al[OCH(CH<sub>3</sub>)<sub>2</sub>]<sub>3</sub>, Sigma–Aldrich, 99.9%) was dissolved in 100 ml of H<sub>2</sub>O at 60 °C. 10 ml of ethylene glycol (Sigma–Aldrich, 99%) was added to this for 10 min. A proper quantity of Cu precursor ([Cu(NO<sub>3</sub>)<sub>2</sub>·2.5H<sub>2</sub>O], Sigma–Aldrich) was put in, depending on the loading quantity. The mixture was stirred for an hour; then, the pH was adjusted to two using HNO<sub>3</sub> to obtain a clear sol. Thereafter, this mixture was stirred continuously for an hour. It was evaporated for approximately 12 h while the pressure was reduced. Finally, gelled solid and powder were dried in an electric oven at 130 °C. The process of manufacturing a catalyst in the impregnation method is as follows. Al<sub>2</sub>O<sub>3</sub> (3 μm, Jonson Matthey) was put in 800 ml of H<sub>2</sub>O at 60 °C, followed by stirring for 10 min. The Cu precursor was inserted in it by the specified quantity. After stirring for 2 h, it was evaporated for 4 h and dried in an electric oven for approximately 12 h. The washcoat, which was manufactured in the sol–gel method [19] and the above impregnation method, was milled for 2 h. The sizes range between 50 and 150 μm by the milling. Coating was conducted in our own laboratory's method. The washcoat was dissolved in H<sub>2</sub>O. This was stirred for 2 h. This substrate was dipped vertically into a suspension for 2 min. In order to load the same quantity of the washcoat, the catalyst was dried and then weighed before and after dipping. All catalysts were calcined at 500 °C for 2 h; then, they were reduced with H<sub>2</sub> at 400 °C for 2 h, but it is not included some kinds of binders and stabilizers. So finally the catalyst samples are lower loading amount of washcoat than other previous research, but the original coating method was kept for the actual applicability to the emission after-treatment devices for the vehicle. Fig. 1 is a graph showing the result of X-ray diffraction measurements of the Cu10%(imp)/Al<sub>2</sub>O<sub>3</sub> and Cu30%(Sol-gel)/Al<sub>2</sub>O<sub>3</sub> catalysts prepared by the impregnation and sol–gel method, respectively.

### 2.2. Experimental apparatus

A laboratory-scale model of a normal-pressure fixed-bed gas catalyst reactor was used to evaluate the performance of the reacting catalysts. The model gas catalyst reactor was comprised of a gas supply part, catalyst reaction part, analyzer, and controller, as shown in Fig. 2. The catalytic reactor used a cylindrical quartz tube

**Table 1**  
Specifications of the catalysts.

Catalysts	Cu (g)	Al[OCH(CH <sub>3</sub> ) <sub>2</sub> ] (g)	Method	Loading (g)
Cu10%	0.3	11.38	Sol–gel	0.2–0.3
Cu20%	0.6	10.12	Sol–gel	
Cu30%	0.9	8.85	Sol–gel	
Cu40%	1.2	7.59	Sol–gel	
Catalysts	Cu (g)	r-Al <sub>2</sub> O <sub>3</sub> (g)	Method	Loading (g)
Cu5%	0.3	5.7	Imp	0.2–0.3
Cu10%	0.6	5.4	Imp	



**Fig. 1.** X-ray diffraction patterns of Cu catalysts.

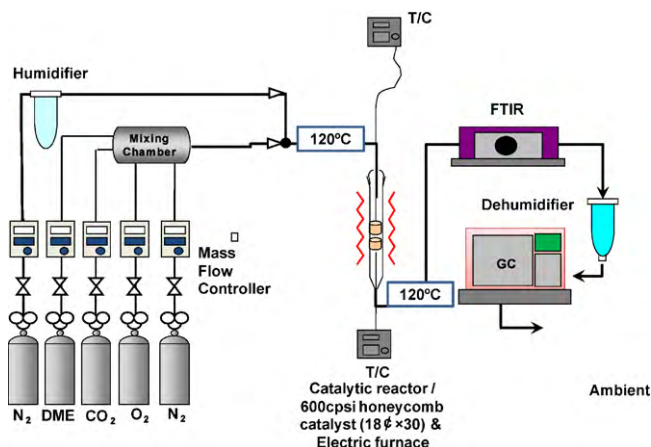


Fig. 2. Schematic diagram of DME catalytic reaction apparatus.

of 19 mm inner diameter and 350 mm length, with the catalysts fixed to the center of the reaction tube. Two catalysts of the same size of  $180 \times 30$  mm (600 cPsi, cordierite) were each used in the experiment. The catalysts were heated using an electric furnace, and their temperatures were measured using a K-sheath type of thermocouple of 1.6 mm diameter. FTIR (Fourier Transform Infrared Spectroscopy, HI2000, MIDAC), GC (Gas Chromatograph, HP 6890, HP), and NDIR (Non-dispersive infrared, 554JK, HORIBA) were used to analyze the component gases. FTIR confirmed the participation of water in the reaction, and GC analyzed DME,  $\text{CH}_4$ , and CO using a FID (Flame Ionization Detector) and an HP-PLOT Q (Agilent) column. Also,  $\text{H}_2$  was analyzed using a TCD (Thermal Conductivity Detector) and a molecular sieve 5A (Agilent) column. Ar was used as a carrier gas for GC. NDIR analyzed  $\text{CO}_2$ . The supplied gas was accurately controlled by an MFC (Mass Flow Controller) and then uniformly mixed in a mixing chamber. The DME supply flow rate was controlled by a pressure control valve at the outlet of the pressure vessel, a check valve was installed to prevent backflow, and a filter was installed to filter foreign substances. A designated concentration of water was supplied to the reaction tube using saturated steam pressure, and water was separated via a water separator before the measurement of the concentration at the GC in order to eliminate disruption by water during the measurement of the gas concentration. All the lines from the preheater to the concentration measurement in the reaction system were heated to  $120^\circ\text{C}$  in order to prevent water condensation.

### 2.3. Experimental method

The DME conversion ratio of catalysts in the model gas reactor was obtained by using a formula for the conversion ratio (%) =  $\frac{([\text{DME}_{\text{in}}] - [\text{DME}_{\text{out}}])}{[\text{DME}_{\text{in}}]} \times 100$  by measuring the gas concentration at the inlet and outlet of the catalytic reactor. The product selectivity (%) was obtained using a formula:  $\frac{(\text{reactant gases selectivity})}{(\text{H}_2 + \text{CO} + \text{CH}_4 + \text{CO}_2 \text{ selectivity})} \times \text{DME conversion ratio (in \%)}.$  The factors used in the experiment were the space velocity (SV), and  $\text{H}_2\text{O}$ ,  $\text{O}_2$ , and  $\text{CO}_2$  concentrations, etc., whose details are shown in Table 2. Experiments were conducted

Table 2  
Parameters for evaluation of catalytic activity.

Parameter	SV ( $\text{h}^{-1}$ )	500, 2500, 5000	1000
Gas composition	DME (%)	1%	0, 2, 1%
	$\text{H}_2\text{O}$ (%)	5%	0, 3, 8, 5, 10%
	$\text{O}_2$ (%)	0%	0, 1, 5%
	$\text{CO}_2$ (%)	0%	7%
	$\text{N}_2$	Balance gas	

in a steady condition of a total flow rate of 283 mL/min of reaction gases and catalyst temperature of  $200\text{--}500^\circ\text{C}$ .

### 3. Results and discussion

Fig. 3 shows the variation of the DME conversion ratios with the kind of catalyst and supply DME concentration. The experimental conditions were (a) DME 0.2% and (b) DME 1% at  $\text{SV} = 1000 \text{ h}^{-1}$  and  $\text{H}_2\text{O} = 5\%$ . The catalysts used were Cu (sol) at 10, 20, 30, and 40% manufactured in the sol-gel method and Cu (imp) at 5 and 10% manufactured through the impregnation method. In case (a), viz., supply condition of DME 0.2%, the Cu30 and 40% catalysts manufactured in the sol-gel method yielded a conversion ratio of over 60% at  $400^\circ\text{C}$ ; however, the Cu10 and 20% catalysts yielded a lower conversion ratio. In case (b), viz., supply condition of DME 1%, the Cu30% catalysts yielded the best conversion ratio, and the Cu30% (sol) catalysts yielded the best conversion ratio. The amount of the loading Cu on  $\text{Al}_2\text{O}_3$  is limited in a sol-gel method. In spite of the higher amount of Cu, the limitation of Cu can only be combined with  $\text{Al}_2\text{O}_3$  in a crystal state. From the of TEM analysis result, we could see that the dispersion of Cu catalyst was decreased at over 40 wt% Cu loading, because there was grown to agglutination of Cu particles. However, the amount of Cu was varied according to the method of preparation of the catalyst.

Fig. 4 shows the surface images of the Cu5 and 10% (imp,  $\times 30 \text{ k}$ ) and Cu30% (sol,  $\times 100 \text{ k}$ ) catalysts through a SEM (SEM, S4700HITACHI, Japan). In general, DME forms methanol after hydrolysis at the Lewis acid sites of  $\text{Al}_2\text{O}_3$ , thereafter creating  $\text{H}_2$  and  $\text{CO}_2$  via catalysts such as Cu [15]. As a result of the SEM images, the catalysts manufactured in the impregnation method show large growth of the surface washcoat and large Cu particles. The catalysts manufactured in the sol-gel method render the Cu particles difficult to observe regarding their washcoat surfaces at

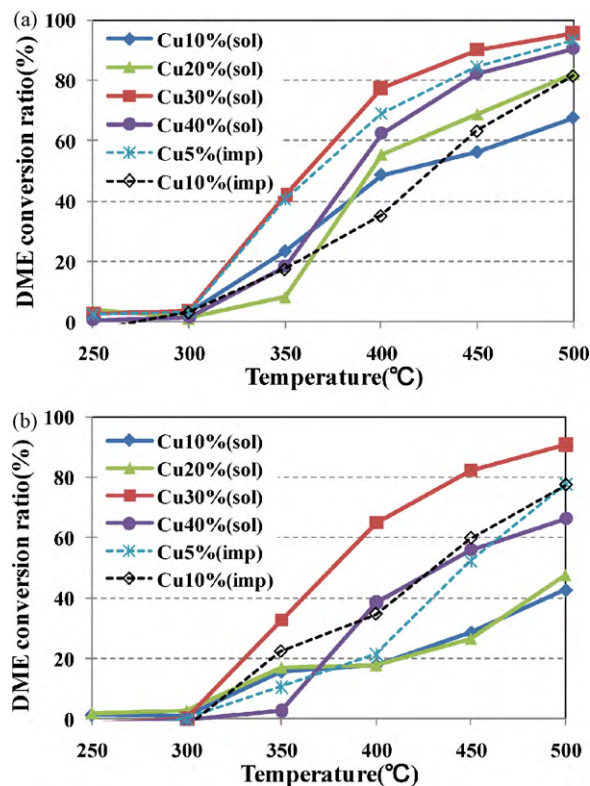
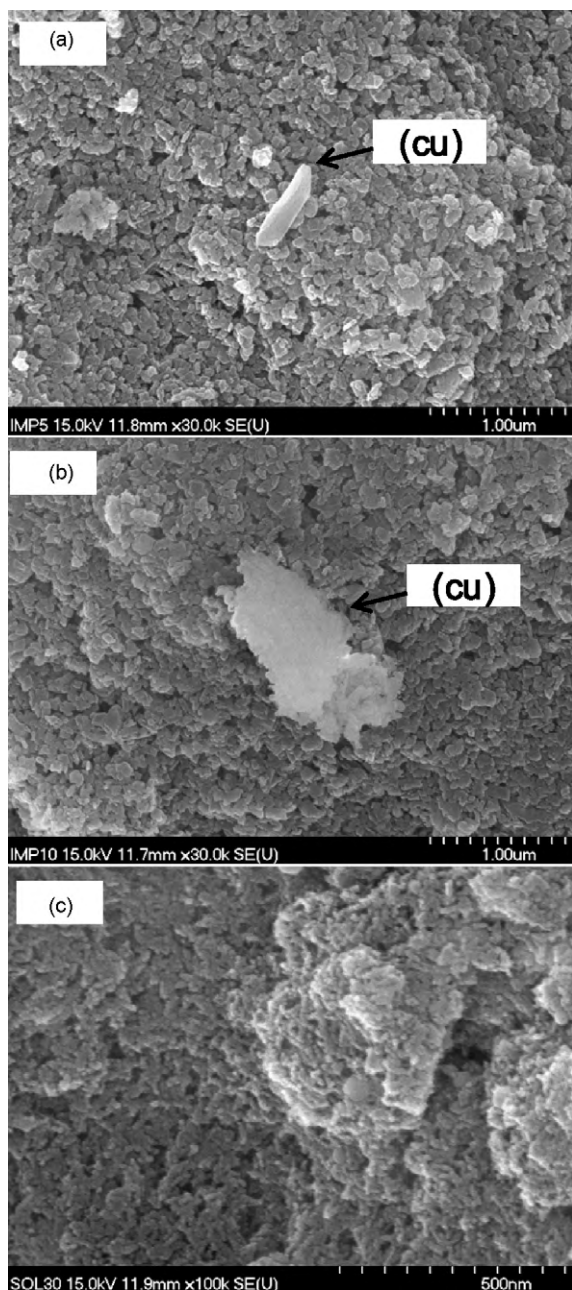


Fig. 3. DME conversion ratio according to catalysts and DME quantity ( $\text{SV} = 1000 \text{ h}^{-1}$ ,  $\text{H}_2\text{O} = 5\%$ ) (a) DME 0.2% (b) DME 1%).





**Fig. 4.** SEM images of the catalysts ( $\times 30, 100$  k) (a) Cu5% (imp), (b) Cu10% (imp), and (c) Cu30% (sol).

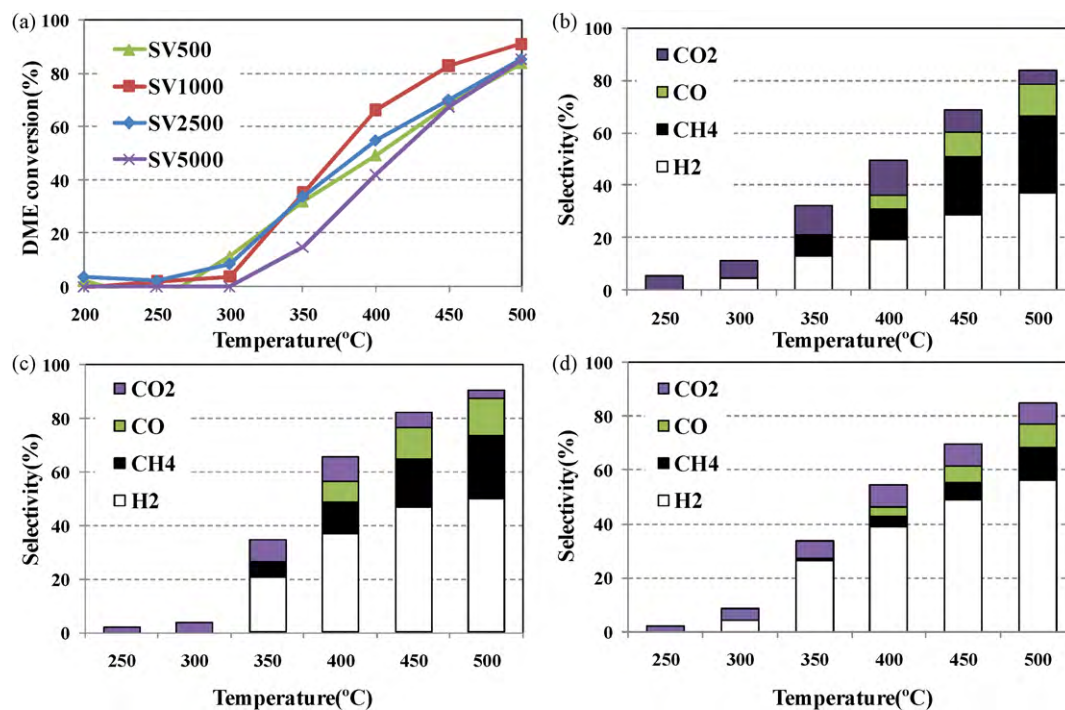
30 k, which were thus analyzed via magnification to 100 k. The size of the Cu surface crystals is similar to that for  $\text{Al}_2\text{O}_3$ , making it difficult to distinguish between  $\text{Al}_2\text{O}_3$  and Cu, whose dispersion is also high. This shows why a sol–gel method yields a higher DME conversion ratio than an impregnation method for manufacturing catalysts. The result of screening tests regarding the variation of the DME conversion ratio with the catalyst manufacturing methods and Cu loading quantities indicated that Cu30% (sol) showed the best conversion ratio. The subsequent experiments were conducted using Cu30% (sol); repeated experiments yielded no difference in the conversion ratio. Fig. 5 shows the DME conversion ratio and reaction product selectivity when SV is raised from  $500 \text{ h}^{-1}$  to  $5000 \text{ h}^{-1}$ . The DME conversion ratio was highest for  $\text{SV}1000 \text{ h}^{-1}$ , and the  $\text{H}_2$  selectivity increased as SV increased. However, there is no plot

of the  $\text{H}_2$  selectivity with regard to  $\text{SV} = 5000 \text{ h}^{-1}$ , that was decreased with the DME conversion and  $\text{H}_2$  selectivity. This seems to be the case because an increase in SV can enhance the selectivity of hydrogen that is created by the partial oxidation of DME. However, there is a limit on the increase in SV; therefore, a greater increase in SV will entail a trade-off of reaction products [21,22]. At  $450^\circ\text{C}$ , the  $\text{H}_2$ ,  $\text{CH}_4$ , and CO selectivities were: 28, 22, and 10 at%  $\text{SV} = 500 \text{ h}^{-1}$ ; 47, 17, and 12 at%  $\text{SV} = 1000 \text{ h}^{-1}$ ; and 49, 6, and 6 at%  $\text{SV} = 2500 \text{ h}^{-1}$ . The  $\text{H}_2 + \text{CO}$  selectivity is highest at  $\text{SV} = 1000 \text{ h}^{-1}$ , which is likely to be favorable as an LNT reductant formation condition, but it is difficult to determine the optimum condition for an LNT reductant considering the DME conversion ratio and  $\text{CH}_4$  selectivity.

Fig. 6 shows the DME conversion ratio and reaction product selectivity when the  $\text{H}_2\text{O}$  concentration is respectively 0% (part (a)), 5% (part (b)), and 10% (part (c)).  $\text{H}_2\text{O}$  concentration of 5–10% conditions is the most important reason for selecting a steam reforming method among the DME reforming methods. The exhaust emissions from diesel vehicles contain 5–10%  $\text{O}_2$ , which can be used for partial oxidation reactions, but  $\text{O}_2$  was used to the steam reforming for higher  $\text{H}_2$  selectivity. Although the steam reforming reaction is an endothermic reaction, it is the reason requiring heat source by all means, the exothermic reaction of DME oxidation on the LNT of an after-treatment system of vehicles is expected to act as the heat source for the SR catalyst. A concentration of 0% yielded the lowest DME conversion ratio and  $\text{H}_2$  selectivity, while there was no significant difference under  $\text{H}_2\text{O}$  of 5 and 10%. The presence of  $\text{H}_2\text{O}$  at 5 and 10% occasioned a water-gas shift reaction, reduced CO selectivity, and increased  $\text{H}_2$  selectivity. At  $350^\circ\text{C}$ , the  $\text{H}_2$  selectivity under  $\text{H}_2\text{O}$  5% and 10% was 19.5 and 7.5%, respectively; these values differ. This shows that  $\text{H}_2\text{O}$  at 5% was rather helpful for  $\text{H}_2$  selectivity and that  $\text{H}_2\text{O}$  at 10% increased the  $\text{CO}_2$  selectivity a little by promoting a perfect reaction. However, at a high temperature of  $500^\circ\text{C}$ , the  $\text{H}_2$  selectivity under  $\text{H}_2\text{O}$  at 5 and 10% was 50 and 47.5%, respectively. Meanwhile, the CO selectivity was not particularly affected by the  $\text{H}_2\text{O}$  concentration.  $\text{H}_2\text{O}$  at 3.8% yielded a slightly higher DME conversion than  $\text{H}_2\text{O}$  of 5% in reactions but the  $\text{H}_2$  selectivity exhibited a similar result. It was shown that  $\text{H}_2$  selectivity almost obeyed the thermodynamic consideration of earlier DME steam reforming [23].

Fig. 7 shows the variation of the DME conversion ratio and product selectivity with the  $\text{O}_2$  concentration under the presence of  $\text{H}_2\text{O}$  at 5%. The exhaust emissions from diesel vehicles contain 5–10% of  $\text{O}_2$ . In order to examine the high temperature pyrolysis characteristics of DME, the catalysts whose substrates were not loaded with washcoat were marked as blanks. This blank shows a DME conversion ratio of about 25% at  $500^\circ\text{C}$ . The variation of the  $\text{O}_2$  concentration from 0 to 1% resulted in no significant difference in the DME conversion ratio. The condition (c) of  $\text{O}_2$  being 1% increased only the  $\text{CO}_2$  selectivity via a partial oxidation reaction at  $350^\circ\text{C}$ , and then proceeded with no more oxidation reactions; rather, it reduced the  $\text{CO}_2$  selectivity and increased the  $\text{H}_2$ ,  $\text{CH}_4$ , and CO selectivities at more than  $350^\circ\text{C}$ . This is because an  $\text{O}_2$  concentration of 1% proceeds with a partial oxidation reaction (Eq. (4)) [24]. However, the condition (d) with an  $\text{O}_2$  concentration of 5% or more proceeds with the oxidation reaction, generating no CO and increasing the  $\text{CO}_2$  selectivity. In this manner, it is judged that Cu catalysts form  $\text{H}_2$  without perfect oxidation into  $\text{H}_2\text{O}$  even under the presence of sufficient  $\text{O}_2$  concentrations, which is a differentiating feature of Cu catalysts in relation to prior catalysts.

Fig. 8 shows the DME conversion ratio and  $\text{H}_2$  selectivity under the presence of  $\text{CO}_2$  in the reactant gas. The exhaust emissions from diesel engines also contain 5–10% of  $\text{CO}_2$  [25], which it generally blocks catalyst reactions, so its effect on the production

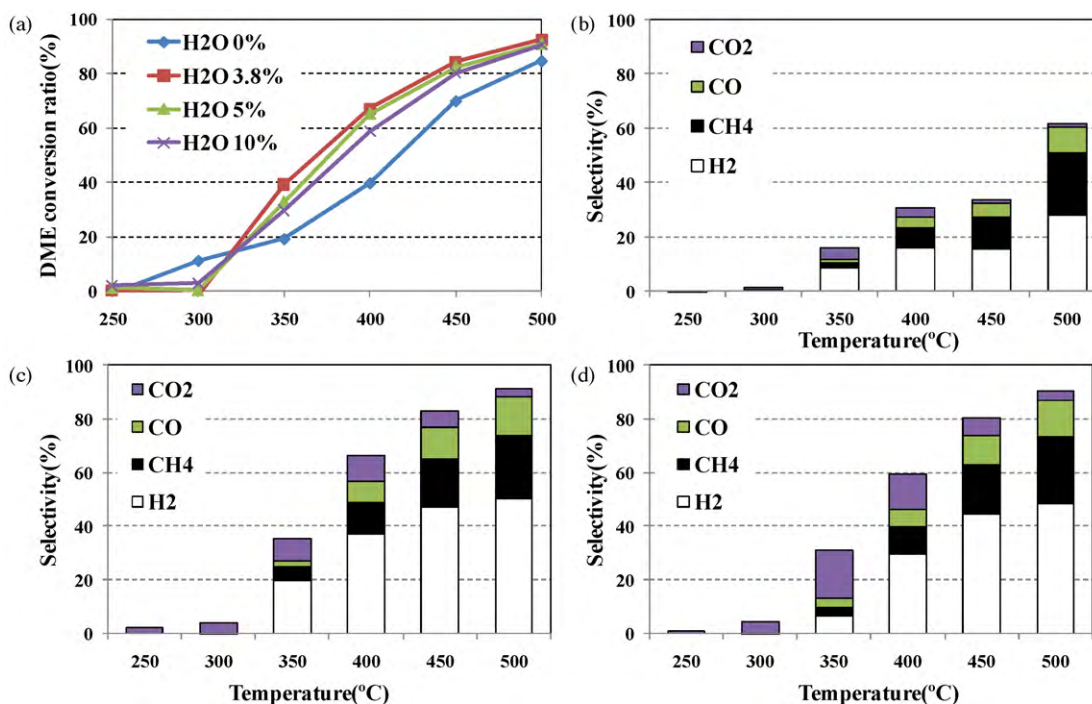


**Fig. 5.** DME conversion and conversion ratio of formation gases according to SV (DME = 1%, H<sub>2</sub>O = 5%, (a) DME conversion ratio, (b) selectivity of formation gases at SV = 500 h<sup>-1</sup>, (c) at SV = 1000 h<sup>-1</sup>, (d) at SV = 2500 h<sup>-1</sup>).

of H<sub>2</sub> in a DME steam reforming reaction is a very important experimental factor. In the presence of CO<sub>2</sub>, the DME conversion ratio and CO selectivity exhibited no significant variation, and the conversion ratio was over 90% regardless of the presence of CO<sub>2</sub> at a temperature of 500 °C. The selectivity of H<sub>2</sub>, an intermediate product, showed a maximum difference of 7% at 350 °C, and the

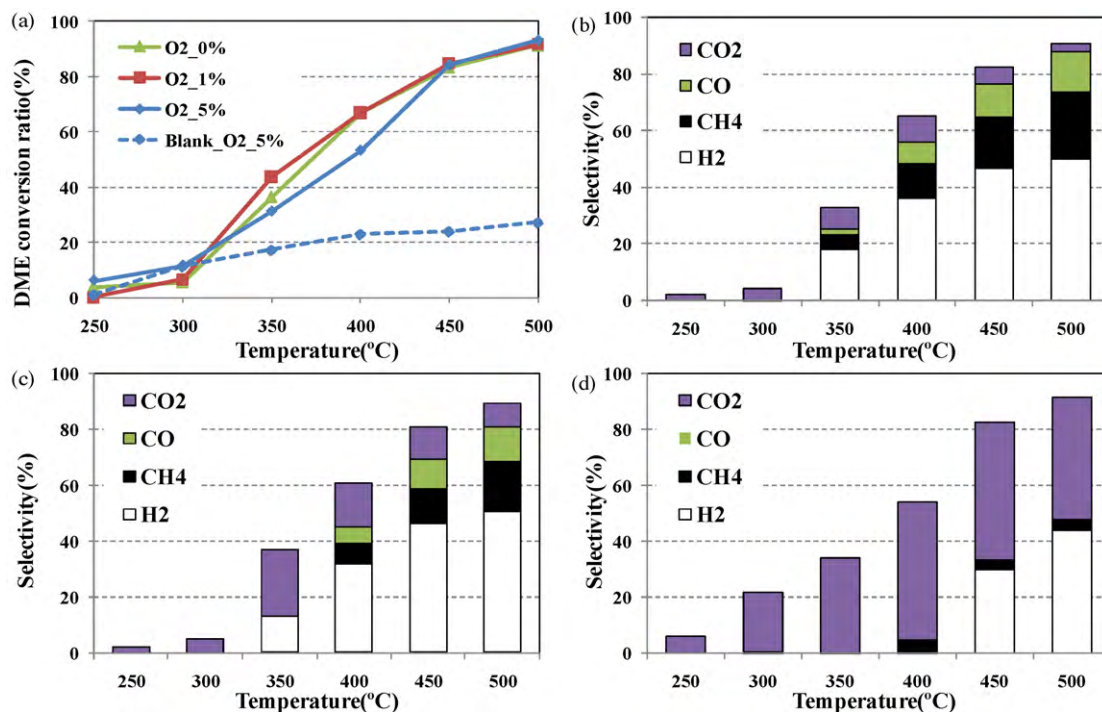
presence of CO<sub>2</sub> had an adverse effect on the H<sub>2</sub> selectivity. Vehicle emissions incorporate CO, the coexistence of which had no significant effect on the DME conversion ratio and H<sub>2</sub> selectivity, unlike the case of CO<sub>2</sub>.

In the future, various catalysts will be reviewed to improve the DME conversion ratio and H<sub>2</sub> selectivity.

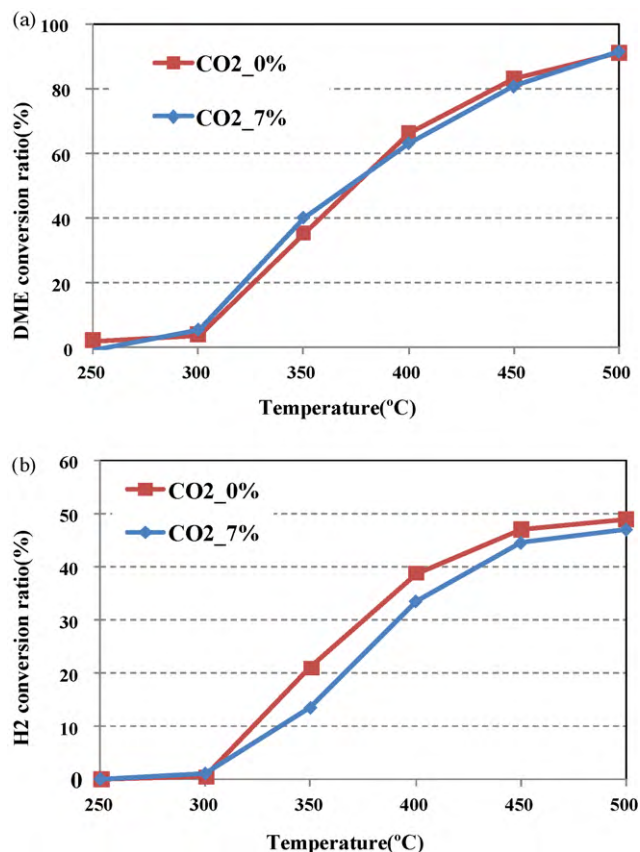


**Fig. 6.** DME conversion and conversion ratio of formation gases according to H<sub>2</sub>O concentration (SV = 1000 h<sup>-1</sup>, DME = 1%, (a) DME conversion ratio, (b) selectivity of formation gases at H<sub>2</sub>O = 0%, (c) at H<sub>2</sub>O = 5%, and (d) at H<sub>2</sub>O = 10%).





**Fig. 7.** DME conversion ratio of formation gases according to  $O_2$  concentration ( $SV = 1000 \text{ h}^{-1}$ , DME 1%,  $H_2O$  5%), (a) DME conversion ratio, (b) selectivity of formation gases at  $O_2 = 0\%$ , (c) at  $O_2 = 5\%$ , and (d) at  $O_2 = 10\%$ .



**Fig. 8.** DME conversion ratio and  $H_2$  selectivity in presence of  $CO_2$  ( $SV = 1000 \text{ h}^{-1}$ , DME = 1%,  $H_2O$  = 5%).

#### 4. Conclusions

This study aims to investigate various parameters that affect the formation of hydrogen in order to efficiently use hydrogen as a reductant for LNT catalysts for DME diesel engines. A monolithic honeycomb-type Cu catalyst was used in this study. The considered parameters included the effect of the manufacturing methods for the catalyst washcoat, space velocity, and concentrations of  $O_2$ ,  $H_2O$ ,  $CO_2$ , etc. The DME conversion ratio and  $H_2$  selectivity were highest under Cu30% manufactured in the sol-gel method, showing a conversion ratio of about 78% at a reaction temperature of  $400^\circ\text{C}$  (DME = 0.2%). The  $H_2$  selectivity varies with the SV and is optimized at  $SV = 2500 \text{ h}^{-1}$ ; however, it is necessary to select an optimum SV depending on the kind of catalyst. The presence of  $H_2O$  at 5 and 10% in the reactant gas decreased the CO selectivity and increased the  $H_2$  selectivity due to a water-gas shift reaction. Further,  $H_2O$  at a concentration of 5% or more had no significant effect on the DME conversion ratio and  $H_2$  selectivity. The coexistence of  $CO_2$  in the reaction had no significant effect on the DME conversion ratio, but it slightly decreased the  $H_2$  selectivity. Also in a simulating condition of the vehicle emission, we could find the optimum condition of the DME steam reforming to form  $H_2$  and CO, and the location of the steam reforming catalyst in the vehicle after-treatment system is in the front of the LNT catalyst.

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